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SEDIMENT TRANSPORT STUDIES IN THE DELTA-MENDOTA CANAL AND THE CALIFORNIA AQUEDUCT[1/]

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ABSTRACT

The Delta-Mendota Canal (DMC), completed in 1951, has experienced capacity problems, currently attributed to a combination of design deficiency and the accumulation of sediment and clam deposits. Investigations over a number of years have concluded that sediment in the water is bound by the excreta of the Asiatic clam (Corbicula manilensis). This accumulation of sediment-clam deposits causes a reduction in canal capacity, in addition to the design deficiency loss.

In the present investigation, sediment transport characteristics of the DMC and the California Aqueduct were compared. The investigation indicated that there were significant differences in the two intake facilities. Approximately 70 percent of the sediment entering the Aqueduct was deposited in Clifton Court Forebay and Bethany Reservoir, while only 10 percent was deposited in the DMC intake channel. The difference in sediment deposition was attributed to differences in design and operation of the intake facilities.

The concentration of total suspended solids entering the DMC was found to vary directly with total delta export and vary inversely with the solids concentration of the Sacramento River, the primary source of delta export water.

It appears that there is deposition of sediment in the channels leading to the export facilities during the winter and that resuspension of this sediment occurs in the summer during periods of high delta export.

OBJECTIVES OF REPORT

This report summarizes the findings of studies conducted in 1973-74 on the sediment-clam deposition problem in the Delta-Mendota Canal (DMC) and makes recommendations for potential alternatives for

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controlling the problem. The 1973-74 studies characterized sediment transport in the DMC and California State Aqueduct. The objectives of the studies were to determine the source(s) and quantities of suspended sediments entering the two conveyance systems, compare physical and operational differences, and determine the extent and location of sediment deposition.

INTRODUCTION

The Delta-Mendota Canal and the California Aqueduct are the major water conveyance facilities of the Federal Bureau of Reclamation's Central Valley Project and the California State Water Project. The DMC provides a major supply of water for agriculture on the west side of the San Joaquin Valley. The DMC conveys water from the Sacramento-San Joaquin Delta south 186 km (116 mi) to the Mendota Pool, on the San Joaquin River. Since 1968, water has been delivered from the DMC at km 111.5 (MP 69.30) to the San Luis Project through the O'Neill Pumping Plant. The canal is concrete lined for 153 km (95 mi), has a 14.65 m (48 ft) bottom, 1.5:1 side slope and an average water depth of 4.9 m (16 ft). The design capacity of the canal is 130 m^3/s (4,600 ft^3/s) and the design water velocity is 1.16 m/s (3.8 ft/s). The water flows through a 4.0 km (2.5 mi) intake channel to the Tracy pumps which lift the water 61.0 m (200 ft) into the concrete lined portion of the canal. The pumps operate continuously during the irrigation season which extends from January through October (figure 1).

Since the canal approached design capacity operation in the 1960's it has had continuing capacity problems. The canal has been dewatered for repairs and removal of sediment and biological growth accumulations on six different occasions. Furthermore, there are indications that the canal capacity problem is increasing. Removal of sediment-clam deposits averaged about 14,000 yards/year, prior to 1966, and 20,000 yards/year since 1968.

The severity of the canal capacity loss culminated in the Bureau raising the canal sidewall by 0.46 m (1.5 ft) in 1962, in order to provide 111 m^3/s (4,200 ft^3/s) canal capacity to O'Neill Pumping Plant. This temporarily alleviated water demand requirements but did not resolve the canal capacity loss problem related to sediment-clam deposition.

The costs for dewatering-cleaning operations are substantial. The physical removal of sediments from the canal has been estimated to cost from $43,000 to $100,000 per cleaning operation. Additional costs include the extra costs of pumping sediment-laden water and the undocumented but substantial physical damage to the canal each time it is dewatered.

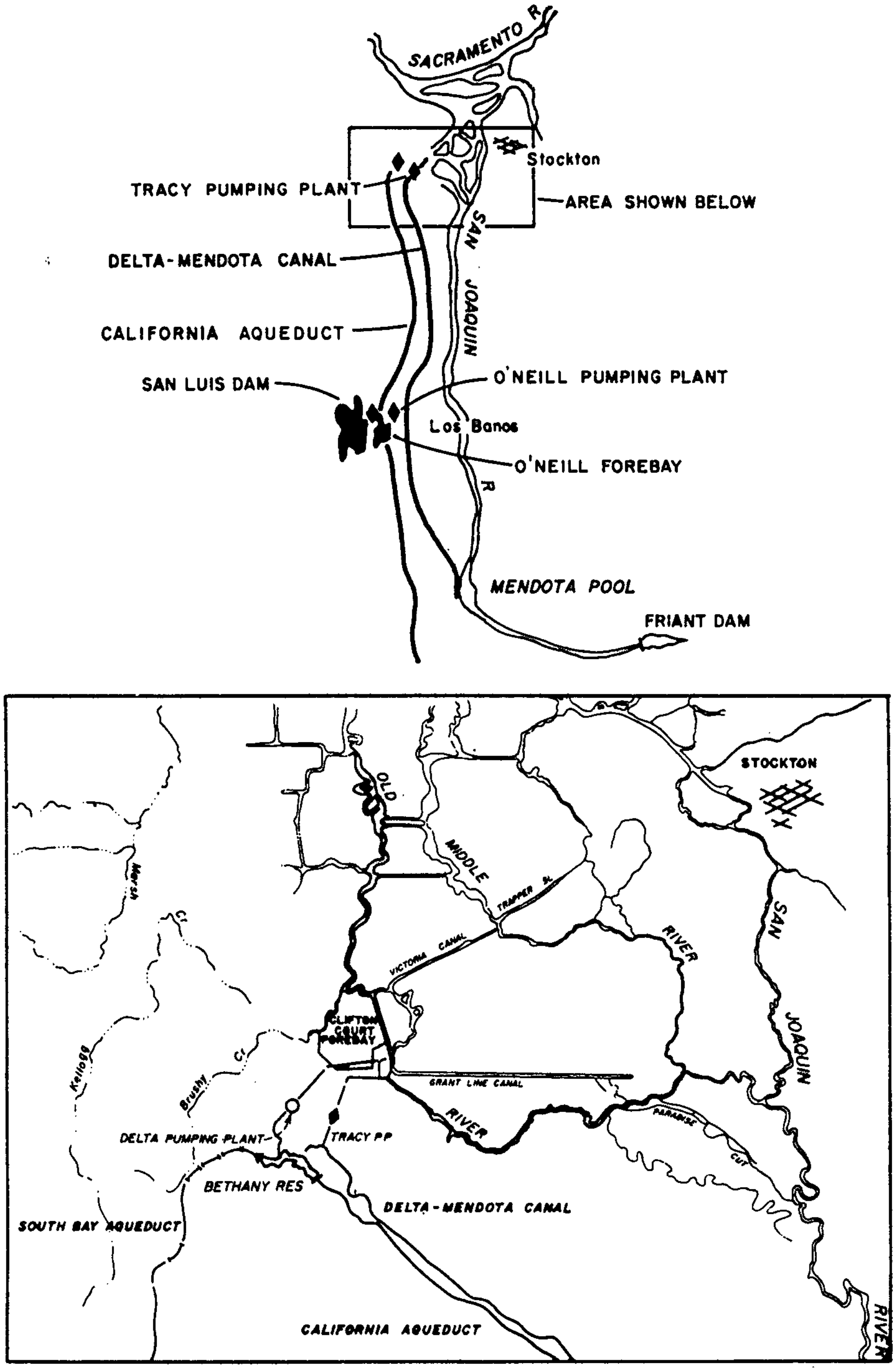

FIGURE 1—Sacramento-San Joaquin Delta illustrating Delta-Mendota Canal and State Aqueduct expert facilities

Fortunately, in the past, water demands have been less than maximum canal capacity and water demands have been met. However, in the near future, water demands are expected to reach canal capacity. Reduction in canal capacity due to sediment-clam deposition and loss during the 8 to 10 weeks required for dewatering and cleaning operations will result in loss of water sales. The potential loss in water sales is projected to be from 400,000 to 450,000 acre-feet per year at an approximate cost of $3.50 to $7.50 per acre-foot.

A number of studies have been conducted to determine the cause(s) of canal capacity loss. Hebert (1958) reported that clean canal capacity was 15 percent less than original design capacity and that capacity was reduced by an additional 6.5 percent due to the accumulation of sediment and filter feeding organisms - the Asiatic clam, Corbicula, and an amphoid, Corophium. Prokopovich (1962) attributed buildup of clam sediments as having their origin from three possible sources: (1) inorganic and organic material pumped into the canal from the delta, (2) organic growth, including clams, amphoids, bryozoa, sponges, and other organisms transported into the canal from the delta, and (3) sand, clay, and organic sediment originated locally and transported into the canal through drain inlets, bank erosion, and wind. Subsequent dewatering and cleaning operations were investigated and reported on by Prokopovich (1964, 1965, 1967, 1969, 1973a, 1973b) Prokopovich and Hebert (1964) and Swain and Prokopovich (1969). They concluded that the Asiatic clam, Corbicula manilensis, binds sediments together in the form of excreta which prevents the sediments from passing freely down the canal. These studies culminated in a contract with the California Academy of Sciences, San Francisco, California, to conduct a 2-year biological investigation of the canal (Eng, 1975). In support of this biological study, the Water Quality Branch of the Bureau of Reclamation concurrently conducted a water quality investigation (Lentz, 1975). During the past 18 years, considerable speculation has been directed toward the possible effects the filter feeding organisms have on sedimentation, with little attention directed toward the source of sediments and the physical features of the DMC which are influencing sedimentation.

The California State Water Project was constructed during the 1960's to transport water from the Feather River in the Sacramento Valley, southward along the west side of the San Joaquin Valley, to provide supplemental water supply for the Southern San Joaquin Valley and Southern California. The delta facilities are adjacent to the Tracy Pumping Plant and intake channel and the Aqueduct parallels the DMC from near Tracy to the O'Neill Forebay (figure 1). The Aqueduct has a 14.65 m (48 ft) bottom, 1.25:1 side slope, 9.15 m (30 ft) water depth and a capacity of 283 m^3/s (10,000 ft^3/s). The delta facilities include Clifton Court Forebay (C.C.) which has a surface area of 810 ha (2,000 acres) and an average water depth of 3 to 3.6 m (10 to 12 ft), the Delta Pumping Plant and Bethany Reservoir which is immediately down canal from the pumps, is about 1.6 km (1 mi) long, has a water depth varying from 5 to 20 m (16 to 65 ft) and a surface area of 80 ha (200 acres).

The State Water Project began operation in the fall of 1967. The Delta Pumping Plant operates during periods of off-peak power. The basic pumping schedule of operation in 1973 was from 10 p.m. to 7 a.m., Monday through Thursday, and from 10 p.m. Friday to 7 a.m. Monday, except for the period from 1:30 p.m. to 10 p.m. Saturday.

The intake channels of both the DMC and Clifton Court Forebay connect to Old River, the most westerly San Joaquin River branch in the delta. Inflow into the DMC intake channel is unregulated, the only physical structure being the Tracy Fish Screen Facility. A gated structure regulates the flow into Clifton Court Forebay. Old River is under tidal influence and the gates are opened only during high tide to permit water inflow. This operation takes advantage of the tidal current and provides a higher average water elevation in Clifton Court, thereby reducing the total pump lift into Bethany Reservoir.

While Old River is the major conveyance channel for export water supply, water flows through a number of delta channels leading to the two pumping plants. Essentially all of the flow of the San Joaquin River, in excess of local delta demands, is exported. Additional export water is obtained from the Sacramento River.

METHODS

A field study was conducted on July 30, 31, and August 1-3, 1973, to determine the extent of sediment and clam accumulation in the State system and develop methods of collecting sediment samples.

Dredge samples were collected from Clifton Court, Bethany Reservoir, and 64 km (40 mi) of the Aqueduct using the California Academy of Science's Lyman and Peterson dredges that were being used in their DMC Biological Study. A recording fathomer was also used to make bottom profiles of Clifton Court and Bethany Reservoir. These readings were compared to design specifications to determine the extent of sediment-clam buildup in the two reservoirs (Arthur and Cederquist, 1973a).

Sig-a-motor automatic time sequence composite water samplers were used to collect sediment-water samples of the Clifton Court inlet gates and the fish screen, on the DMC Intake Channel. Three samplers were located at the Clifton Court gates and were operated to collect water samples from 0.3 m (1 ft) beneath the surface, at mid-depth, and 0.3 m (1 ft) off the bottom when the gates were open. The timing mechanism of each sampler was programmed to collect water for 10 minutes, of each 44 minute interval. A fourth sampler was located at the fish screen on the DMC and collected water from mid-depth. Grab samples were collected from near the top, mid-depth, and near the bottom at both locations at 3- to 4-hour intervals. Turbidity of the samples was measured using a Hach 2100 turbidity meter, and then the samples were stored on ice, in the dark, for return to the USBR laboratory where total and volatile suspended solids were analyzed according to Standard Methods (1971).

A second 14-day field study was conducted from September 12 to 26, 1973, (Arthur and Cederquist, 1973b), to collect water-sediment samples from three locations in the DMC and three locations in the Aqueduct. Samplers were located at the fish screen, the Tracy Pump discharge, km 5.6 (mi 3.50) and at check 12, km 102.94 (mi 63.98) on the DMC; and at Clifton Court Inlet, the Delta Pump discharge, km 4.83 (mi 3.00) at check 1, the outlet for Bethany Reservoir, km 9.49 (mi 5.90) on the Aqueduct. The samplers were programmed for 10 minutes of every 44-minute interval, collected water from mid-depth and were wired into the Aqueduct control system so as to operate only when water was flowing through the conveyance facilities. The preliminary study had shown sediment was completely mixed in passage through the control gates and the fish screen and similar turbulent mixed sites were selected for all six samplers.

As a result of this study, monthly total and volatile suspended solids analyses were added to the DMC Water Quality Investigation (Lentz, 1975) for the period from September 1973 to October 1974.

RESULTS AND DISCUSSION

The following sections summarize sediment transport studies conducted during 1973-74 on the DMC and Aqueduct.

Sediment Transport in the California Aqueduct

Dredge sampling was conducted in conjunction with fathometer profiling in both Clifton Court and Bethany Reservoir. Very few clams were found in Clifton Court and these were confined to hard bottom areas away from the inlet. Apparent sediment deposition was detected in a number of areas. Two shallow water areas, 1-1.5 m (3 to 5 ft) were found, one near the inlet and the other near the channel leading to the delta pumps. Asiatic clams and a number of shallow deposits of soft black mud were found in Bethany Reservoir. Bethany Reservoir was formed by damming a number of small valleys in the foothills of the Coast Range Mountains, creating a long narrow lake containing a series of shallow and deep water areas. Clams were confined primarily to shallow water areas and sediment deposition to the deeper areas.

The concrete lined portion of the Aqueduct was sampled at locations similar to where sediment-clam deposits were found in the

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DMC using the Lyman dredge (an Ekman modified by the California Academy of Sciences for the DMC biological study). No deposits of sediment or clams were found in the first 21 km (13 mi) of the canal. However, a number of moderate sandy sediment and clam deposits were found between km 21 and 61 (mi 38).

The concentration of total suspended solids entering Clifton Court Forebay averaged 51 mg/l for the grab samples and 44 mg/l for the composite samples collected during the August 1-3 study. During the 14-day period in September, the average was 49 mg/l at the Clifton Court inlet, 17 mg/l at the Delta pump discharge and 14 mg/l at the Bethany Reservoir outlet at check 1 (table 1). This represented a 72 percent reduction in sediment load between the intake and check 1.

Table 1

California Aqueduct Sediment Loading
September 12 to 26, 1973

	TSS	VSS	NVSS
C.C.	49 mg/l	8 mg/l	41 mg/l
Inlet	133 lbs/acre-foot	22 lb/acre-foot	111 lbs/acre-foot
Delta	17 mg/l	5 mg/l	12 mg/l
Pump head	46 lbs/acre-foot	14 lbs/acre-foot	32 lbs/acre-foot
Check 1	14 mg/l	4.4 mg/l	9.6 mg/l
	38 lbs/acre-foot	12 lbs/acre-foot	26 lbs/acre-foot

There was also a change in composition of the solids, from 84 to 69 percent nonvolatile suspended solids indicating a higher percent loss of inorganic than organic solids in Clifton Court Forebay and Bethany Reservoir. This decrease in suspended solids load and inorganic content of the solids could have several effects. First of all, canal water velocity may be great enough to carry a higher percent of the remaining load through the canal. Secondly, the reduced turbidity, resulting from the reduction in sediment load, may increase the potential for attached and suspended algal growth, while at the same time reducing conditions necessary for clam growth. Since neither Corbicula nor Corophium were found in Clifton Court Forebay, it appears probable that the filter feeding organisms are unable to survive in the Forebay, presumably because of the sedimentation.

Sediment Transport in the Delta-Mendota Canal

The suspended solids concentration in the DMC during the 14-day study in September averaged 64 mg/l at the fish screen, 59 mg/l at the Tracy pump discharge, and 52 mg/l at check 12 (table 2). The August 1-3 samples collected at the fish screen averaged 66 mg/l, total suspended solids. The difference indicated a 10 percent dropout in the intake channel and another 10 percent dropout between the Tracy pumps and check 12, with 80 percent passing on down the canal. The character of the solids changed little, from 86 to 83 percent nonvolatile solids.

Table 2

Delta-Mendota Canal Sediment Loading
September 12 to 26, 1973

	TSS	VSS	NVSS
DMC Intake	64 mg/l 175 lbs/acre-foot	9 mg/l 25 lbs/acre-foot	55 mg/l
Tracy Pump Head MP 3.50	59 mg/l 156 lbs/acre-foot	8 mg/l 22 lbs/acre-foot	51 mg/l 134 lbs/acre-foot
MP 63.98	52 mg/l 142 lbs/acre-foot	9 mg/l 25 lbs/acre-foot	43 mg/l 117 lbs/acre-foot

In summary, the amount of suspended solids entering the Aqueduct during the September study averaged 133 lbs/acre-foot, while the load entering the DMC averaged 175 lbs/acre-foot (tables 1 and 2). However, in the State system, solids load entering the canal at check 1 was reduced to 38 lbs/acre-foot, while the solids load entering the DMC at the pump discharge was 156 lbs/acre-foot.

Possible Sediment Sources

Total delta water export has increased greatly since 1966. DMC export has increased from an average of 1,650,000 in 1966 to 2,177,000 acre-feet in 1974, while the California Aqueduct export has increased from 910,000 acre-feet since the first year of operation in 1968 to 1,860,000 acre-feet in 1974. The result has been an increase in sediment removal during dewatering-cleaning operations to an average of 20,000 yd^3 annually, compared to 14,000 yd^3/yr during the 1956-1966 period, see table 3. The increased sedimentation rate in the DMC appeared to be directly proportional to the increase in delta export pumping.

Measurement of suspended solids at the Tracy pump discharge (September 1973 to September 1974) indicated that the concentration of solids was low during the winter when delta export was low, and high during the summer, when export was high (figure 2). The seasonal solids concentration variation in the DMC was similar to the seasonal variation in the San Joaquin River at Vernalis, but varied inversely with the concentration of suspended solids in the Sacramento River at Sacramento (figures 2 and 3). This would seem

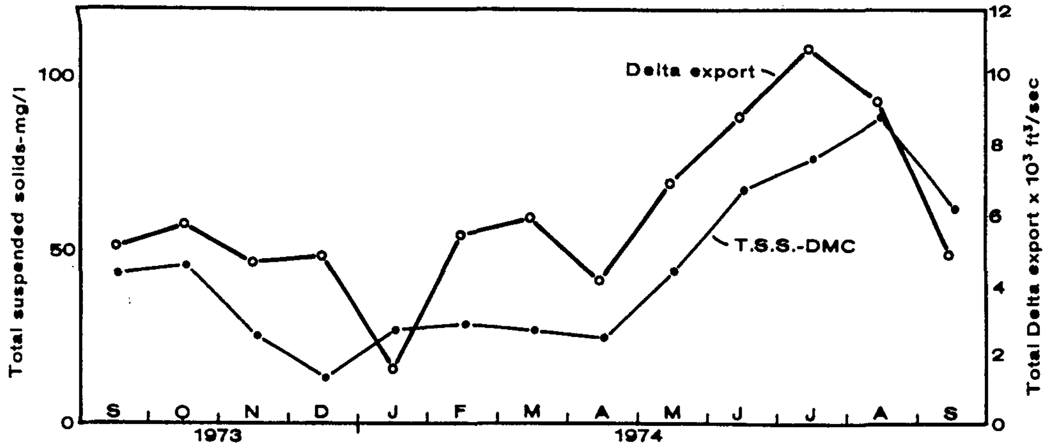

FIGURE 2—Comparison of average total delta export and average total suspended solids entering the Delta-Mendota Canal (USBR data)

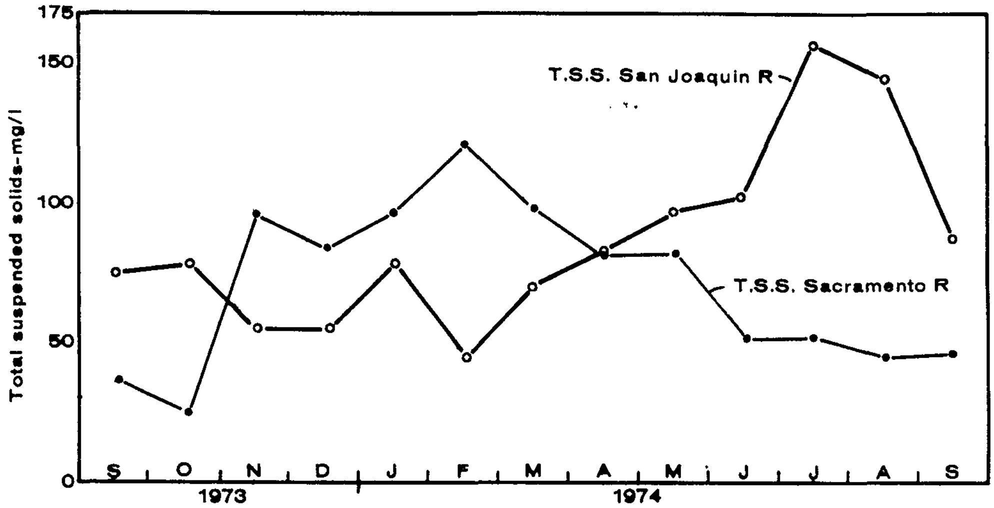

FIGURE 3—Average monthly total suspended solids in the San Joaquin River at Vernalis and Sacramento River at Sacramento (USGS data)

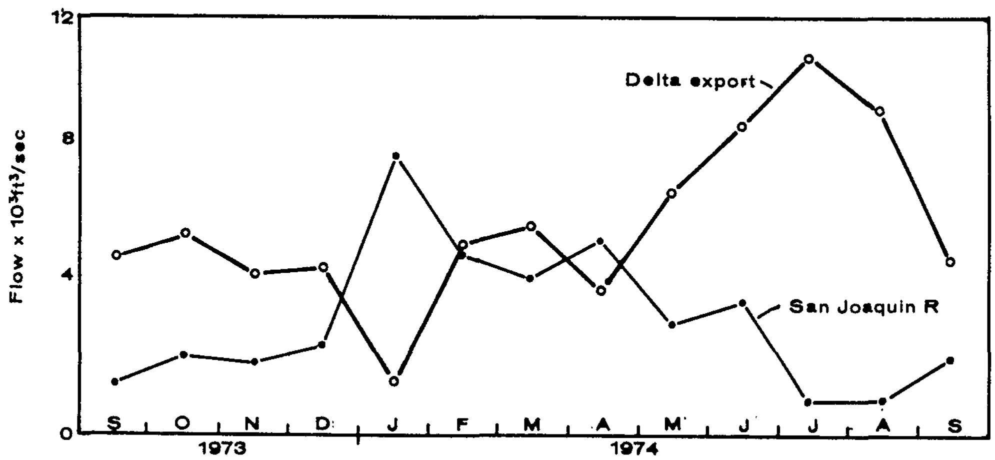

FIGURE 4—Comparison of average total delta export and average San Joaquin River flow at Vernalis (difference between export and river flow made up by Sacramento River flow)

to indicate that the San Joaquin River was the major source of suspended solids in the DMC. However, as illustrated in figure 4, during periods of high export, the flow in the San Joaquin River entering the delta, not allowing for delta consumption, was only 10 to 20 percent of total export and the remaining supply was from the Sacramento River.

Table 3

Wet volume of bottom sediments on the invert of the DMC measured during dewaterings
Data are from Prokopovich (1965, 1967, 1973a, b) and Prokopovich and Hebert (1964).
Units are cubic meters (cubic yards)

Year of Dewatering	km 5.63-93.77 (MP 3.50-58.28)	km 93.77-112.65 (MP 58.28-70.01)	O'Neill Intake Channel km 111.50 (MP 69.30)	Total
1955/56	-	-	-	-
1960/61	51,990 (68,000)	-	-	51,990 (68,000)
1962/63	7,800 (10,200)	13,685 (17,900)	-	21,485 (28,100)
1964/65	6,115 (8,000)	11,160 (14,600)	-	(22,600)
1965/66	12,540 (16,400)	11,850 (15,500)	-	24,390 (31,900)
1969/70	50,845 (66,500)	15,290 (20,000)	30,275 (39,600)	96,410 (126,100)
1972/73	29,590 (38,700)	10,015 (13,100)	19,115 (25,000)	58,720 (76,800)

During the winter, November to March, the suspended solids concentration of the water entering the DMC averaged less than 30 mg/l, but averaged 60 mg/l in the San Joaquin and 90-100 mg/l in the Sacramento River. During the high summer export season, April to September, suspended solids in the DMC averaged 60 to 70 mg/l, over 100 mg/l in the San Joaquin and less than 50 mg/l in the Sacramento River. This indicates a deposition of suspended solids during the winter as water is transported through the delta to the DMC intake and a resuspension of the deposited solids during the summer during periods of high delta export.

CONCLUSIONS

1. The concentration of suspended solids entering the Delta-Mendota Canal is directly related to delta export and inversely related to total sediment load in the source water.

2. The increase in suspended sediments concentration with increased delta export is probably the result of resuspension of materials in the channels leading to the DMC intake facilities.

3. Deposition of sediments in the DMC, during the study, was approximately 10 percent of the total entering the canal. However, the amount depositing in the canal probably depends upon sediment input and pumping rates.

4. The facility design and operation criteria of the Federal and State projects have a significant effect on sediment transport in the two systems. Clifton Court and Bethany Reservoirs serve as sedimentation basins for the State Aqueduct, reducing sediment-clam input to the Aqueduct.

5. Removal of sediments prior to the pumping facilities on the DMC should reduce sedimentation and concentration of filter feeders, *Corbicula* and *Corophium*, in the Delta-Mendota Canal. However, the reduced turbidity may increase attached algal growth.

RECOMMENDATIONS

1. A study should be conducted to determine the specific source(s) of sediments entering the Delta-Mendota Canal and California Aqueduct from the delta channels. A possible study might be to measure sediment transport in all of the delta channels leading into the intake facilities under different export regimes, tidal phases, and delta outflow conditions.

2. In order to prevent deposition in the conveyance systems and/or reduce the food supply for filter feeding organisms, sediment removal should be accomplished prior to entering the delta export facilities. In regards to this, further evaluation should be conducted to compare feasibility and costs of present methods of restoring the Delta-Mendota Canal capacity with alternative methods of sediment control. Possible alternatives might include: (1) utilization of an island adjacent to the intake facilities as a sediment basin, (2) deepening of the delta channels leading to the intake facilities with provisions for removing sediment on a periodic basis, (3) utilization of a mechanical device to dredge the canal while it is operating, and (4) dual utilization by USBR and DWR of Clifton Court Forebay with appropriate modifications for sediment removal.

Economic consideration of the above alternatives should be based on the time schedule for the proposed Peripheral Canal, which should reduce the sediment load reaching the export facilities.

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